EXPERIMENTAL DETERMINATION OF CREEP FATIGUE LIFE OF 316L STAINLESS STEEL PIPE

KHAIRUL AZHAR BIN MOHAMMAD

FK 2011 142
EXPERIMENTAL DETERMINATION OF CREEP FATIGUE LIFE OF 316L STAINLESS STEEL PIPE

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MASTER OF SCIENCE
UNIVERSITI PUTRA MALAYSIA

2011
EXPERIMENTAL DETERMINATION OF CREEP FATIGUE LIFE OF 316L STAINLESS STEEL PIPE

By

KHAIRUL AZHAR BIN MOHAMMAD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

December 2011
DEDICATION

Firstly, I would like to thank to Allah Most Gracious, Most Merciful for giving His blessing with this opportunity and protecting me to complete this research and preparation of this thesis. I always pray to Allah s.w.t to give me the strength and strong-minded as fulfill and achieve the research as a part of my life.

Secondly, this thesis is gratefully dedicated to my beloved parents who have been given financial and moral support without they never failed to give attention, never bored and pray for me during my works in finishing my thesis.

Lastly, I would like to express gratitude to all my friends for without them I would not be here and much less finishing the thesis.
Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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December 2011

Chairman : Associate Professor Aidy Ali, PhD
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Component of engineering structures operating at high temperature such as jet engine, pressure vessels, nuclear reactors, steam and gas turbine including oil and gas plant are subjected to severe thermal and mechanical loading. One of them is tubular structure which is widely used with extensive usage from domestic to aviation. Thus estimate of life and safety is an essential part of design and use. Since the external surface of structures always in contact with environment and is exposed to weather and crash and also due to imperfection during product fabrication, surface crack may exist. The main purpose of this study was to characterize and examine the relative importance of the mechanisms of creep-fatigue interaction on fatigue life in cylindrical structure at high temperature.

Fatigue tests were carried out with constant amplitude at room temperature and at high temperature for smooth specimen in the finite life region of material. Meanwhile constant load and high temperature as 565°C will be imposed to
specimen for creep test. The nature of the hold period (tensile or compressive) affects fatigue life and the surface crack patterns. Creep-fatigue tests with five minutes holds time at maximum tensile stress were conducted using hourglass specimen 

Type 316L stainless steel at temperatures of 565°C. Optical and scanning electron microscopy will be carried out to characterize metallurgical damage in the understanding of microscopic damage mechanics.

The fatigue behaviors of 316L stainless steel from experimental revealed superior behavior compared to as predicted model but still show good agreement with the model. The variation of creep strain rates is clearly show that the secondary creep obeyed with a power of law relationship as constant increase creep rate till the tertiary stages. Experimental results from high temperature low cycle fatigue test show by increasing the temperature there is a reduction in fatigue life of the material. It reduces the fatigue strength of the material. Therefore, the combination of temperature and loading fatigue serve more damage and life reduction in component. It was also determined that crack initiation and propagation at grain boundaries was accelerated under creep fatigue loading condition. It was found that crack initiation occupied a major portion of the failure life under fatigue and creep-fatigue. Creep failure mechanism predominates after short times (>5 minutes).

Finally, the optical and SEM microscope were employed to capture better picture the quality of microstructure and macrostructure of fracture surface, with tensile hold was caused mixed transgranular (TG) + intergranular (IG) propagation. Crack
initiation was also changed to IG by employing a tensile hold which was otherwise TG.
Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PENENTUAN UJIKAJI HAYAT KELESUAN RAYAPAN PADA PAIP KELULI TAHAN KARAT 316L

Oleh

KHAIRUL AZHAR BIN MOHAMMAD

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Komponen struktur teknik beroperasi pada suhu yang tinggi seperti enjin jet, kontena/bejana tekanan, reaktor nuklear, gas turbin dan wap termasuk kilang minyak dan gas mengalami beban termal dan mekanik yang tinggi. Salah satunya adalah struktur berbentuk tiub yang banyak digunakan dengan penggunaan yang luas dari permukaan bumi ke udara. Dengan demikian anggaran hayat dan keselamatan merupakan sebahagian penting dari perancangan dan penggunaan. Sejak permukaan luaran struktur selalu bersentuhan dengan persekitaran dan terdedah pada cuaca dan terkena keretakan dan juga kerana ketidaksepurnaan semasa pembuatan produk, retak permukaan mungkin ada. Tujuan utama dari penelitian ini adalah untuk menggambarkan dan memeriksa kepentingan relatif mekanisme dari interaksi/hubungan kelesuan-rayapan pada jangkahayat lesu pada struktur silinder pada suhu yang tinggi.

Ujian kelesuan dilakukan dengan amplitud tetap pada suhu bilik dan pada suhu yang tinggi untuk spesimen licin di kawasan hayat komponen. Sementara itu beban tetap
dan suhu yang tinggi pada 565°C akan dikenakan kepada spesimen untuk ujikaji rayapan. Sifat tahan masa (regangan atau mampatan) mempengaruhi hayat kelesuan dan corak permukaan retak. Ujian rayapan-kelesuan dengan tahan masa lima minit pada daya regangan yang maksimum dilakukan dengan menggunakan spesimen balang waktu/jam pasir Type 316L stainless steel pada suhu 565°C. Ujian optik dan imbasan mikroskop elektron akan dilaksanakan untuk menggambarkan kerosakan metalurgi dalam memahami mekanik kerosakan mikroskopik.


Akhirnya, mikroskop optik dan imbasan mikroskop electron yang digunakan untuk menangkap gambar yang lebih baik kualiti mikro dan makro struktur permukaan
pecah, dengan daya tahan regangan disebabkan campuran penyebaran transgranular (TG) + intergranular (IG). Permulaan retak juga mengubah menjadi IG dengan melaksanakan daya regangan tahan yang dinyatakan TG.
ACKNOWLEDGEMENTS

First and the foremost, I would like to praise to Allah S.W.T by His Mercy which has given me the opportunity in completion of this research. I would like to thank to Universiti Putra Malaysia for the scholarship given in Special Graduate Research Assistant (SGRA) scheme under grant University (Project No.: 91726) which made me successfully pursuit this degree.

I am deeply indebted to the chairman of supervisory committee, Assoc. Prof. Dr. Aidy Ali and to the co-supervisor, Prof Dr. Ir. Barkawi Sahari and Prof. Dr. Shahrum Abdullah for outstanding advice and assistance throughout the years. With their guidances, I successfully finished my research master with their support and dedication throughout all the stage of the project. I also wish to thank and appreciate the supportive and love of my beloved father named Hj. Mohammad bin Muhammad Salleh, my mother named Hjh. Kamariah binti Hj Mohd Zain and to all of my siblings for their support and blessing during my hardness time in completing this master research.

Special thanks also to Mr. Rashidi and Miss Norita from S.N Machinery Company for provision of materials, Mr. Firdaus bin Abdul Aziz from Universiti of National Malaysia for guidance in conducting creep test and Cik Suraya from TNB Research for undertaking me the experiment of fatigue and creep fatigue and Mr. Ismail bin Abdul Ghani from Chemical Process Engineering Lab I (SEM & EDX) in Department of Chemical & Environmental Engineering, UPM for helping me taking the images SEM and EDX analysis with their gave full cooperation to me until I finished my work. Last but not least, I would like to extend my thanks to my entire friend who had helped in completing in this research project.
I certify that a Thesis Examination Committee has met on 2nd December 2011 to conduct the final examination of Khairul Azhar bin Mohammad on his thesis entitled "Experimental Determination of Creep Fatigue Life of 316L Stainless Steel Pipe" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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Date:
DECLARATION

I declare that the thesis is my original work except for quotations and citation which have been duly acknowledged. I also declare that it has not been previously and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or other institutions.

__________________________________
KHAIRUL AZHAR BIN MOHAMMAD

Date: 2 December 2011
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LIST OF ABBREVIATIONS

H₂S  Hydrogen Sulfide
CO₂  Carbon Dioxide
API  American Petroleum Institute
UV   Ultraviolet
E.R.W Electric Resistance Welded
HTHP High Temperature High Pressure
ASTM American Society for Testing and Materials
SEM  Scanning Electron Microscopy
EDX  Energy Dispersive X-Ray
LCF  Low Cycle Fatigue
HCF  High Cycle Fatigue
S-N  Stress-Life
LDR  Linear Damage Rule
PSB  Persistent Slip Bands
DLDR The Double Linear Damage Rule
SSC  Small Scale Condition
SS   Steady State Condition
TNBR Tenaga Nasional Berhad Research
UTS  Ultimate Tensile Stress
AISI American Iron and Steel Institute
CTOD Crack Tip Opening Displacement

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<td>O</td>
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<td>F</td>
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<td>Cr</td>
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<td>Fe</td>
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<tr>
<td>Co</td>
<td>Cobalt</td>
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<tr>
<td>Na</td>
<td>Natrium</td>
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<td>Cl</td>
<td>Chlorine</td>
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<td>Mo</td>
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<td>Si</td>
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<td>S</td>
<td>Sulphur</td>
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<td>Yb</td>
<td>Ytterbium</td>
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<td>Au</td>
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NOMENCLATURES

LIST OF SYMBOLS

\( kN \) Kilo Newton

\( da/dN \) Fatigue Crack Growth Rates

\( \Delta K \) Stress Intensity Factor

\( \Delta \varepsilon_t \) Total Width of the Loop

\( \Delta \sigma \) Total Height of the Loop

\( \Delta \varepsilon_p \) Plastic Strain Range

\( \Delta \varepsilon_e \) Elastic Strain Range

\( E \) Young's Modulus

\( \sigma_f \) Fatigue Strength Coefficient

\( \varepsilon_f \) Fatigue Ductility Coefficient

\( \sigma_f \) True Fracture Strength

\( \varepsilon_f \) True Fracture Strain

\( b \) Fatigue Strength Exponent

\( c \) Fatigue Ductility Exponent

\( T_M \) Absolute Melting Temperature

\( \dot{\varepsilon}_o \) Strain Rate

\( \sigma_a \) Applied Stress

\( T \) Temperature

\( t \) Time

\( A_n \) Stress Co-efficient

\( Q \) Thermal Activation Energy of Creep
$R$  Bolzmann's Constant

$n$  Stress Exponent

$m$  Time Exponent

$\alpha$  Constant of Order Unity

$B$  Burgers Vector's Magnitude of the Dislocation

$\mu$  Shear Strength

$\Delta F$  Activation Energy

$k$  Boltzmann's Constant

$\tau$  Flow Stress

$\sigma$  Applied Stress

$C^*$  Time-Dependent Energy Integral

$\nu$  Poisson's ratio

$n$  The Norton Law Exponent

$C^*$  Creep Integral

$\Gamma$  Counter-clockwise Contour

MPa  Mega Pascal

$t_{hi}$  Hold Time Period

HCL  Hydrogen Chloride

HNO$_3$  Nitric Acid

$\sigma_{fl}$  Stress of Fatigue Limit
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